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[43] Date: 3/18/86

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## DESCRIPTION OF INVENTION

### 1. Patent Title: Chemical Reactor

### 2. Patent Claims:

Claim 1) The present invention comprises a chemical reactor which is characterized primarily by the fact that it consists of a vertical reaction column filled with a granulated solid catalyst material. The gas required for the reaction is introduced into the top section of the reactor, and a downwards flow of reaction gas through the interior of the reactor is established. The reaction which takes place is exothermic in nature. The generated heat of reaction is removed from the system with the aid of the latent heat of vaporization of water, which is at saturation temperature, and which is in contact with the outer walls of the aforementioned reaction column. The reaction column consists of several sections of varying column diameter: the diameter of the upper part of the reaction column, where a relatively large amount of reaction heat is produced, is comparatively small; while the diameter of the lower portion of the column, where less reaction heat is liberated, is larger.

Claim 2) The present invention comprises a chemical reactor which is characterized primarily by the fact that it consists of a vertical reaction column filled with a granulated solid catalyst material. The gas required for the reaction is introduced into the top section of the reactor, and a downwards flow of reaction gas through the interior of the reactor is established. The reaction which takes place is exothermic in nature. The generated heat of reaction is removed from the system with the aid of the latent heat of vaporization of water, which is at saturation temperature, and which is in contact with the outer walls of the aforementioned reaction column. The reaction column consists of several sections of varying column diameter: the diameter of the upper part of the reaction column, where a relatively large amount of reaction heat is produced, is comparatively small; while the diameter of the lower portion of the column, where less reaction heat is liberated, is larger. In addition, in the lowest part of the reactor, where the water employed to remove the reaction heat from the system is fed in, the column diameter once again decreases.

**3. Area of Use:** The present invention comprises a chemical reactor, intended for use in carrying out exothermic reactions with initial synthesis gases containing several components, in the presence of a solid granular catalyst material. For instance, the proposed reactor may be utilized in the synthesis of methanol from initial hydrogen and carbon monoxide (or carbon dioxide).

**Current Technology (Chemical Reactors Utilized in Methanol Synthesis):** The reactors currently utilized in the industrial production of methanol and other gases, via exothermic reactions, employ a number of devices and techniques to regulate the temperature of the gas within the reactor, which tends to increase as a result of the liberated heat of reaction. For example, in Fig. #9, below, where there is a graph-form representation of the conditioning of the equilibrium concentration of methanol within the system by the prevailing reaction pressure and temperature levels (for a molar concentration ratio of  $H_2 : CO = 4 : 1$ ), it can be seen that reaction temperature exerts a significant effect on the value for methanol equilibrium concentration, in the methanol synthesis reaction in question. As reaction temperature is increased, there is a corresponding decrease in the equilibrium concentration of methanol, where, in turn, leads to substantial economic losses for the production operation involved. In addition, even when suitable catalyst materials are employed, there are strict limits to the attainable reaction rate: reaction rate is directly related to reaction temperature, and, as reaction temperature is decreased, there will be a corresponding reduction in attained reaction rate. Many industrial operations currently use different catalyst materials, in an attempt to maintain the reaction temperature within the optimal interval. The authors of the present invention carried out the synthesis of methanol from initial hydrogen, carbon monoxide and carbon dioxide, with the aid of a copper catalyst. In order to ensure that this procedure would be cost-effective on an industrial scale, the optimal temperature interval ( $220 \sim 280^\circ C$ ) was employed. The gas pressure level (total pressure) employed in conjunction with this optimal temperature range was  $50 \sim 300 \text{ kg/cm}^2 \text{ G}$ . In regard to catalyst materials best suited for use in this reaction, the use of other, more modified catalyst materials is permissible under the specified reaction conditions; no specific limitations have been established here in this regard.

One well known solution for the problem of temperature control in exothermic reactors is provided in Japanese Patent 38568 (1982). For a detailed illustration of this proposed solution, refer to Fig. #10, below, which comprises a schematic representation of the reactor specified in the cited patent. This chemical reactor consists of the following: a reaction column, tightly fastened to an upper support [1] and a lower support [2], all of which is enclosed in a hermetic sheath [9]. The interior of the reaction column is filled with catalytic material [4]. The initial gas mixture, pre-heated to the optimal temperature interval, and containing hydrogen, carbon monoxide and carbon dioxide (and, where necessary, other components), is fed into the reactor, under pressure, through an upper gas feed aperture [5]. A flow of gas through the reactor, in a downwards direction, is thereby established. By this means, the catalytic (methanol synthesis) reaction is initiated. In the system under discussion, the heat generated in the course of the exothermic reaction is removed from the reaction column [3] with the aid of the latent heat of vaporization of water [7], which is at the appropriate pressure level and at saturation temperature, and which is in contact with the outer walls of the reaction column [3] (the

removed heat is employed in the generation of water vapor). By this means, the temperature of the gas within the reaction column is constantly maintained within the optimum range. As can be seen in Fig. #10, the proposed reactor includes other features: for instance, the reaction gas, after entering the reaction column [3] through the upper inflow aperture [5], flows down through the column, and finally exits through an outflow line [6] in the lower part of the reactor. In the proposed heat-exchange system, water [7'] is flowed through a water inflow line [7] into the reactor, where it removes the generated reaction heat from the reactor. The water vapor which is generated in the course of this procedure is then removed from the reactor through a water vapor outflow line [8].

In the chemical reactor referred to above, there are tightly-fastened upper [1] and lower [2] partitions; these partitions each have a central aperture, to which the reaction column [3] is firmly attached. The reaction column [3] has a constant diameter. Thus, in the system in question, the heat which is produced in the course of the exothermic synthesis reaction is removed by the effect of the latent heat of vaporization of water, which is at saturation temperature. In fact, in the system under discussion, there is no regulation of total reaction volume along the longitudinal axis of the reaction column (in other words, the system in question makes use of a constant flow rate of the reaction gas through the reaction column).

**Inadequacies of the Reactor Described Above:** However, in the upper portion of reactor represented in Fig. #10, when the initial reaction gas is fed into the reaction column [3] filled with catalyst material [4], the methanol concentration level is, in most cases, minimal. The methanol concentration level in this upper part of the reaction column differs markedly from the equilibrium concentration level for methanol. In this part of the reaction column, the methanol synthesis reaction proceeds at a relatively rapid rate, with an associated high level of generated reaction rate. The generated reaction heat passes through the walls of the reaction column and passes into the water [7'] which is circulated through the reactor interior. Thermal control within the system under discussion is achieved by means of the variation of parameters such as the amount of column surface which is in contact with the cooling water, the degree of thermal conductivity of the reaction column walls, column wall thickness, etc. In most cases, the quantity of generated heat and the quantity of transferred heat (cooling rate) exist in a non-equilibrium condition. As indicated below, in Fig. #11 (which provides a schematic representation of the temperature distribution profile along the longitudinal axis of the conventional industrial reactor in question here), the reaction temperature (that is, the temperature of the gas within the reaction column) is higher in the initial (upper) section of the reaction column.

On the other hand, in the lower portion of the reaction column [3] filled with catalyst material [4], the methanol concentration level is not far removed from the equilibrium methanol concentration level. For this reason, the reaction rate in this area is relatively slow, and there is a gradual decrease in the temperature of the gaseous mixture within the column. This decrease in gas temperature is a result of the establishment of an equilibrium state between the quantity of gas generated in the course of the exothermic methanol synthesis reaction, and the quantity of heat removed from the system through the reaction column walls. However, if one considers such a production system in terms of end-product composition, it is clear that, even if the methanol concentration level in

the obtained end-product reaction mixture is increased by as little as 1%, on an industrial scale, there would be an associated substantial economic benefit. For this reason, it is preferable that the rate of reaction gas flow through the end portion of the reaction column be reduced, in order that the contact time of the reaction gas with the catalyst material can be increased.

However, in the case of the standard-type chemical reactor represented below, in Fig. #10, there will be a constant-rate flow of the gaseous reaction mixture through the entire length of the reaction column, as a result of the configuration of the column. For this reason, if the rate of passage of the gaseous mixture through the reaction column is reduced, there will be an excessive overheating of the upper section of the reaction column, per unit column length (unit column length x column cross-section perimeter = unit square of heat emission). This, in turn, leads to the superheating of the gaseous mixture and the catalyst material within the reaction column. As has been well established, catalyst materials are effective only within a specific temperature range. According to the authors' calculations, the maximum temperature at which copper can function effectively as a catalyst in methanol synthesis reactions is 300 - 350°C (this value can be changed through the use of an improved methanol synthesis catalyst). Thus, if, in the standard type synthesis reactor represented above, in Fig. #10, the rate of flow of the gaseous mixture through the reaction column is reduced, the temperature regime in the upper portion of the reaction column will surpass the upper limits of catalyst effectiveness temperature, with obvious adverse results. There is another method available for increasing the contact time of the gaseous mixture with the catalyst material within the reaction column, without reducing the rate of flow of the gaseous mixture through the column - namely, an increase in the length of the reaction column. For this reason, it is common for industrial methanol production facilities to make use of reaction columns 25 to 30 meters in length. However, such a solution has its own set of problems and disadvantages. When the length of the reaction column is increased, contact time with the catalyst is indeed correspondingly increased, but, in order to prevent an undesirable (for the reasons described above: overheating and resultant loss of catalyst effectiveness) reduction in the rate of flow of the gaseous mixture through the column, it is necessary to increase the system pressure, which leads to a substantial increase in the level of resistance to gas stream flow within the reaction column, and an associated increase in system pressure loss and inflow-outflow region pressure differential; this, in turn, substantially increases the load placed on the pumps which maintain the circulation of gas within the system.

**Goal of Invention:** On this basis, the authors of the present invention established as their primary goal the development of a chemical reactor which would not possess the various problems and disadvantages of the reactor described in detail above. More specifically, the established goal of the present invention was the development of a reaction column which would provide an equal temperature distribution along its longitudinal axis. In addition, the reaction column must be equipped with a water feed system in its lower section, to provide the potential for the effective removal of the generated reaction heat from the system.

**Methods Employed in Achieving Goal:** The present invention contains two basic innovations. First, the use of a reaction column with varying diameters along the longitudinal axis - in this case, the upper section of the column is narrower than the lower section. The second innovation consists in the fact that, at the lowest point of the reaction column, the column diameter is again decreased, in order to provide adequate space for the installation of a water feed assembly. More specifically, the present invention consists in the following:

1. The present invention comprises a chemical reactor which is characterized primarily by the fact that it consists of a vertical reaction column filled with a granulated solid catalyst material. The gas required for the reaction is introduced into the top section of the reactor, and a downwards flow of reaction gas through the interior of the reactor is established. The reaction which takes place is exothermic in nature. The generated heat of reaction is removed from the system with the aid of the latent heat of vaporization of water, which is at saturation temperature, and which is in contact with the outer walls of the aforementioned reaction column. The reaction column consists of several sections of varying column diameter: the diameter of the upper part of the reaction column, where a relatively large amount of reaction heat is produced, is comparatively small; while the diameter of the lower portion of the column, where less reaction heat is liberated, is larger.

2. The present invention comprises a chemical reactor which is characterized primarily by the fact that it consists of a vertical reaction column filled with a granulated solid catalyst material. The gas required for the reaction is introduced into the top section of the reactor, and a downwards flow of reaction gas through the interior of the reactor is established. The reaction which takes place is exothermic in nature. The generated heat of reaction is removed from the system with the aid of the latent heat of vaporization of water, which is at saturation temperature, and which is in contact with the outer walls of the aforementioned reaction column. The reaction column consists of several sections of varying column diameter: the diameter of the upper part of the reaction column, where a relatively large amount of reaction heat is produced, is comparatively small; while the diameter of the lower portion of the column, where less reaction heat is liberated, is larger. In addition, in the lowest part of the reactor, where the water employed to remove the reaction heat from the system is fed in, the column diameter once again decreases.

In the examples and explanations provided below, when one or the other of these variants of the present invention is referred to, it will be specified as either Proposal 1 or Proposal 2, on the basis of the preceding paragraphs.

Detailed illustrations of the present invention are provided in the figures and diagrams below. First, in Figs. #1 through #4, an illustration of the variant embodied in Proposal 1 is provided. In Fig. #1, there is a schematic sectional representation of a chemical reactor of the type described in Proposal 1. Fig. #2 contains a diagrammatic representation of a reaction column with varying diameters along its longitudinal axis, which is intended for use with said reactor (Specific Example 1). Fig. #3 depicts another variable-diameter reaction column for use with the aforementioned chemical reactor; Fig. #4 also depicts, in schematic form, another alternative variable-diameter reaction column for use with the Proposal 1 chemical reactor. In Fig. #1, the reference numbers [1] through [9] coincide in

meaning with those discussed above, in conjunction with Fig. #10, which represents a type of chemical reactor currently in widespread industrial use. Therefore, it is necessary only to point out the differences between these two reactors. In the Proposal 1 variant of the present invention, the variable-diameter reaction column [10] consists of a section with a relatively small diameter [10a] and a larger-diameter section [10b]. In Fig. #1, only one of the types of variable-diameter reaction columns is represented in conjunction with the Proposal 1 chemical reactor, although several variant reaction columns are available for use.

A more detailed illustration of the structure of a variable-diameter reaction column is provided in Fig. #2. Here, the initial, unreacted gaseous mixture is fed into the upper section of the variable-diameter reaction column [10], and the reaction rate within this upper section [10a] is relatively high. The length of this section ( $l_1$ ) is adequate for the accommodation of the higher reaction rate; and the diameter ( $d_1$ ) of this initial section [10a] of the reaction column [10] is less than that of the lower section [10b] of said column [10]. This configuration results in an overall decrease in the quantity of heat which must be removed per unit reaction column length (heat exchange per unit squared), and, by this means, it becomes possible to effectively regulate (decrease) the temperature in the initial (upper) section of the reaction column, which is higher owing to the exothermic reaction proceeding there at a relatively high rate. Thus, even when the rate of passage of the gaseous reaction mixture decreases in the lower section of the reaction column, there will not be any overheating in the upper section of the column, and the catalyst material will continue to function properly and effectively.

In order to decrease the temperature of the obtained reaction product to a level at which the reaction rate will increase gradually, the flow conditions within the reaction column [10] are selectively varied by means of changes in column diameter. If, in a given case, the ratio value for diameters  $d_2 / d_1$  is high, the rate of passage of the gaseous reaction mixture through the lower section of the reaction column [10b] will be relatively slow. As a result of this reduction of the flow rate of the reaction mixture through the lower section ( $l_2$ ) of the reaction column, there is a corresponding increase in the contact time for gaseous reaction mixture with catalyst material in that section. By this means, a higher methanol yield rate is obtained than is customary in the reactors of this general type which are currently employed in industrial methanol synthesis procedures. The configuration of the proposed reaction column makes it possible to attain a uniform reaction temperature distribution along the longitudinal axis of the reactor column.

In the lower (end) section of the reaction column (of length  $l_2$  and diameter  $d_2$ ), the reaction temperature (that is, the temperature generated by the liberation of heat in the exothermic synthesis reaction in question here), will be relatively low. For this reason, even when the flow rate of the gaseous reaction mixture through the lower section of the reaction column is reduced, the rate of heat exchange through the reaction column walls is adequate to maintain the desired uniform reaction temperature profile for the column. The excess reaction heat is transferred to the water which is circulating along the outside of the reaction column walls, and is thereby removed from the system. By this means, the optimum reaction temperature can be established and maintained. In addition, as can be seen in Fig. #2, the proposed reaction column has a third section, in its central region, where there is a constant-rate change from one diameter size to the other (narrower to wider). This transition section ( $l_3$ ) is required in order to provide a smooth transition from

diameter region  $d_1$  to diameter region  $d_2$ . The appropriate values for significant reaction column section ratios (including  $l_1/l_2$ ,  $d_1/d_2$ ,  $l_1/d_1$ ,  $l_2/d_2$  and  $l_1/l_2/l_3$ ) are to be calculated on an individual basis for each specific implementation of the proposed chemical reactor; no specific guidelines or restrictions have been established in this regard. The most important precondition in the structural configuration in question here is that  $d_1$  must be less than  $d_2$ .

In Fig. #3, below, there is a representation of a variant type of variable-diameter reaction column, for use with the chemical reactor of Proposal 1, depicted in Fig. #1. This reaction column has three sections of increasing diameter: 10a; 10b; and 10c. Sections [10a] and [10b] in this reaction column are analogous to the same regions in the column described above, and represented in Fig. #2. However, in the present case, at the lower end of section [10b], there is a larger-diameter supplemental section [10c], which has a length of  $l_6$  and a diameter of  $d_4$ . This larger-diameter section [10c] is connected with section [10b] through a second transitional section ( $l_7$ ), which also exhibits a constant-rate diameter change, to allow for a smooth transition from one column diameter region to the next.

Fig. #4, below, provides yet another variable-diameter reaction column for use with the chemical reactor depicted in Fig. #1. In this case, the reaction column, like the variant represented in Fig. #2, consists of an upper section [10a], of smaller diameter, and a larger-diameter lower section [10b]. However, the column represented in Fig. #4 differs from the column in Fig. #2 by its inclusion of an upper larger-diameter section ( $d_3$ ), which is attached to the upper partition [1] of the reactor; thus, for this variant,  $d_3$  is greater than  $d_1$ .

Proposal 2 of the present invention is illustrated in Figs. #5 and #6, below. In Fig. #5, there is a sectional view of a variable-diameter reaction column for use in Proposal 2. Fig. #6 provides a schematic representation of another variable-diameter column for use in Proposal 2. The reaction column represented in Fig. #5 has the same structure as that represented in Fig. #2, with a single exception - there is a supplemental section [10d] at the bottom of the reaction column, which has length  $l_4$  and diameter  $d_3$ . In this case,  $d_3$  is less than  $d_2$ . Section [10d], which is the site of the connection of the cooling water supply line, is connected with section [10b] by means of another transition section ( $l_5$ ) with a constant-rate diameter variation.

As can be seen in Fig. #1, the proposed chemical reactor is situated inside a hermetic housing [9], with the cooling water feed line [7] being situated in the lower part of this housing. However, in cases in which the need arises for the installation, within the reactor housing [9], of radially-oriented supplemental equipment (as is often the case in industrial practice), then, in cases in which the  $d$  value is relatively large, there will be an extremely narrow interstitial space between the walls of the housing [9] and the reaction column [10]. For example, in the configuration represented below, in Fig. #2, there is very little space for the establishment, within the reactor housing, for the installation of the water feed system. This is the primary reason for the establishment of the modification of the present invention embodied in Proposal 2. As can be seen in Fig. #5, there is a supplemental lower section of the reaction column, of length  $l_4$  and diameter  $d_3$ , where  $d_3$  is less than  $d_2$ . In this variant, the diameter of  $d_3$  may be the same as, or different from, that of  $d_1$ .  $l_5$  represents the constant-rate variation transition region from one reaction column diameter size section to the next, which, as noted above, is required for the

smooth transition from section to section. The outflow aperture for the cooling water [8] is established, in this case, in the upper portion of the reactor housing [9], since, in this position, where the column diameter is relatively small, there will be no problems associated with excessive resistance to movement of the water vapor in a radial direction.

In Fig. #6, there is another specific example of a variable-diameter reaction column. As can be seen in this diagram, the reaction column [10], like that depicted in Fig. #5, consists of a smaller-diameter upper section [10a], a larger-diameter intermediate section [10b], and a supplemental lower section of a smaller diameter [10d]. However, the column represented in Fig. #6 possesses sections with diameters  $d_3$  and  $d_6$ , which are smaller than both  $d_1$  and  $d_2$ .

In Fig. #7, there is a representation of a variant of the proposed chemical reactor. In this reactor, the gaseous reaction mixture is fed through an inflow line [5], a junction line [11], and another feed line [12], then passes through the center of the reaction column, and finally reaches the upper section of the reactor [13]. The reaction mixture then enters the reaction column, where it comes into contact with the catalyst material with which the column is filled; by this means, the catalytic synthesis reaction is initiated. Next, the gaseous reaction-product mixture is removed from the reactor through the outflow line [6]. This reactor possesses a variable-diameter reaction column.

As can be seen in Figs. #2, #3 and #5, in section  $l_1$  of the proposed chemical reactor, there is a relatively high rate of flow of the gaseous reaction mixture, and a lower rate in section  $l_2$ . This configuration makes possible the attaining of a satisfactory temperature for the formation of the desired reaction products, without the destruction or disabling of the catalyst material. In Fig. #8, there is a graph-form representation of the conditioning of methanol concentration level by system temperature, for specific chemical reactor models; while, in Fig. #9, there is a graph which represents the conditioning, for the proposed reactor, of methanol concentration by system temperature and pressure levels. The data provided in Fig. #8A are for the standard type chemical reactor represented in Fig. #10, and which provides for a uniform rate of passage of the gaseous reaction mixture through the reaction column; while Fig. #8B provides data for the reactor proposed in the present invention. Point (a) on these graphs represents the temperature and methanol concentration level at the moment that the gaseous reaction mixture enters the upper section of the reaction column. The methanol synthesis reaction proceeds at a rapid rate in this upper section of the column. As indicated in the temperature profile in Fig. #11, the temperature exhibits an initial marked increase, followed by a decrease as the reaction products accumulate. The decreasing temperature reaches point (c), in the lowest portion of the reaction column. The methanol is at the point (c) temperature when it is removed from the reactor. In the standard type reactor, which its requirement that the temperature at point (b) must not exceed the maximum catalyst effectiveness temperature, and that the rate of passage of the gaseous reaction mixture through the reaction column must be held constant, it is not possible to obtain a high methanol concentration (yield) value at point (c). On the other hand, in the case of the proposed chemical reactor (see data provided in Fig. #8B), point (a) has the same signification as in Fig. #8A; next the gaseous reaction mixture passes through the upper section of the reaction column, with diameter  $d_1$  and length  $l_1$  (in Fig. #8, this corresponds to the (a)-(e) interval). Since the flow rate of the reaction mixture is relatively high in this initial reaction column section, it is possible to effectively regulate gas temperature. This makes possible the effective



implementation of a wide range of processing (reaction) conditions. In the lower section of the reaction column, with diameter  $d_1$  and length  $l_1$  (in Fig. #8, this corresponds to the (e)-(f) interval), there is a relatively low flow rate for the gaseous reaction mixture, and, as a result, a relatively long period of contact of the reaction mixture with the catalyst material. As a result, at the end point (f), which corresponds to the lowest part of the reaction column, a high methanol concentration value is achieved.

Chemical reactors which are suitable for use in the industrial-scale synthesis of methanol are typically quite expensive. However, the proposed chemical reactor is cost-effective, and also offers the potential for a fairly wide range of uses. The proposed reactor contains a reaction column which is filled with a solid granulated catalyst material. The gaseous reaction mixture is fed into the upper portion of the reaction column, and a downwards flow of reaction gas within the column is established. By this means, the catalytic methanol synthesis reaction is carried out. The surplus heat which is generated in the course of this exothermic reaction is passed through the reaction column walls to a stream of circulating cooling water, by means of which it is removed from the system. By this means, the temperature within the reaction column is maintained within the optimum range. There are no specific limitations for the proposed reactor in regard to reaction column parameters  $d_1$  and  $d_2$ , or  $l_1$  and  $l_2$ . It is also permissible, in the present context, to make use of a multi-section reaction column, of the type represented below, in Fig. #5, with parameters  $d_1$ ,  $d_2$  and  $d_3$ , and  $l_1$ ,  $l_2$  and  $l_3$ . Finally, there are no specific restrictions established here in regard to the use of other types of gaseous reaction mixture, processing temperature and pressure level, quantity of generated reaction heat, type of catalyst material employed, material from which the reaction column is constructed, reaction column width, pressure level of the circulating cooling water within the reactor sheath, etc.

In addition, within the present context, the reaction column is attached to upper and lower partitions, and that, in the attachment regions, the column may possess diameters other than the working diameters. However, it is desirable to bear in mind that the catalyst material must be inserted into and removed from the reaction column through the upper aperture. It should also be kept in mind that, in these insertion and attachment regions, the reaction column must be sufficiently strong to withstand the various physical and mechanical loads to which it will be subjected. For these reasons, the diameter of the reaction column in the attachment regions should not be excessively small.

**Results:** The present invention comprises, as noted above, a reaction column with varying column diameters, with the diameter of the upper part of the column being significantly less than that of its lower section (Proposal 1). As a result of this structural modification, it was found possible to establish and maintain an equal temperature distribution along the longitudinal axis of the reaction column. In addition, in the context of the present invention, the lowest part of the reaction column may have its diameter once again reduced (Proposal 2), in order to provide adequate space for the installation of supplementary equipment, such as, for instance, the inflow site for the cooling water. The disposition of the water feed system ensures a more even distribution of the water stream within the reactor.

**4. Brief Explanation of Illustrations:** In Fig. #1, there is a cross-section of the chemical reactor described here in Proposal 1.

Fig. #2 provides a schematic cross-section view of a reaction column with varying diameters, for use in association with the chemical reactor depicted in Fig. #1.

Fig. #3 comprises another specific example of a reaction column with varying diameters, also intended for use in conjunction with the chemical reactor depicted in Fig. #1.

Fig. #4 comprises another specific example of a reaction column with varying diameters, also intended for use in conjunction with the chemical reactor depicted in Fig. #1.

Fig. #5 comprises a specific example of a reaction column with varying diameters, for use in conjunction with the reactor specified in Proposal 2.

Fig. #6 comprises another specific example of a reaction column with varying diameters, for use in conjunction with the reactor specified in Proposal 2.

Fig. #7 provides a schematic representation of another chemical reactor, previously developed by the authors of the present invention, which makes use of a reaction column with varying diameters.

Fig. #8 provides a graph-form representation of the conditioning of methanol concentration by system temperature.

The graph in Fig. #9 illustrates the conditioning of methanol equilibrium concentration by the prevailing reaction pressure and temperature.

Fig. #10 comprises a cross-sectional representation of a chemical reactor of the type presently in widespread industrial use.

Fig. #11 provides a diagrammatic representation of the structure of a well known type of chemical reactor, and a representation of the temperature distribution profile along the longitudinal axis of the associated reaction column.

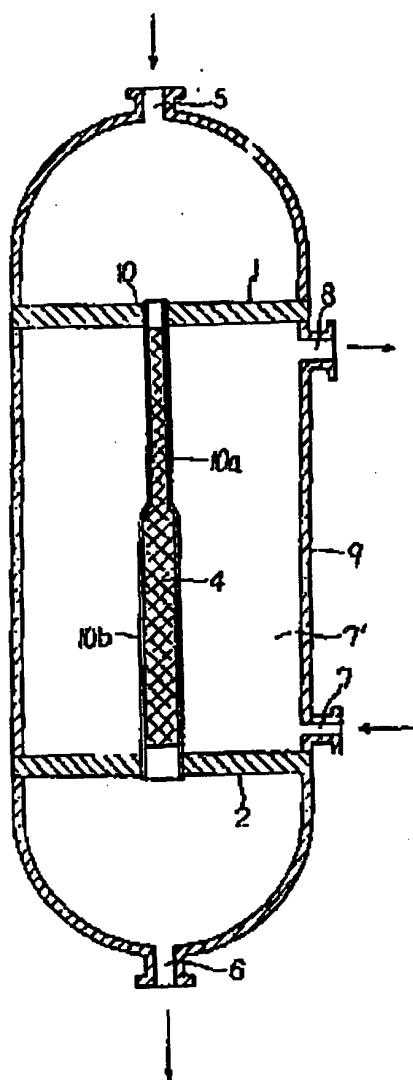


Fig. #1

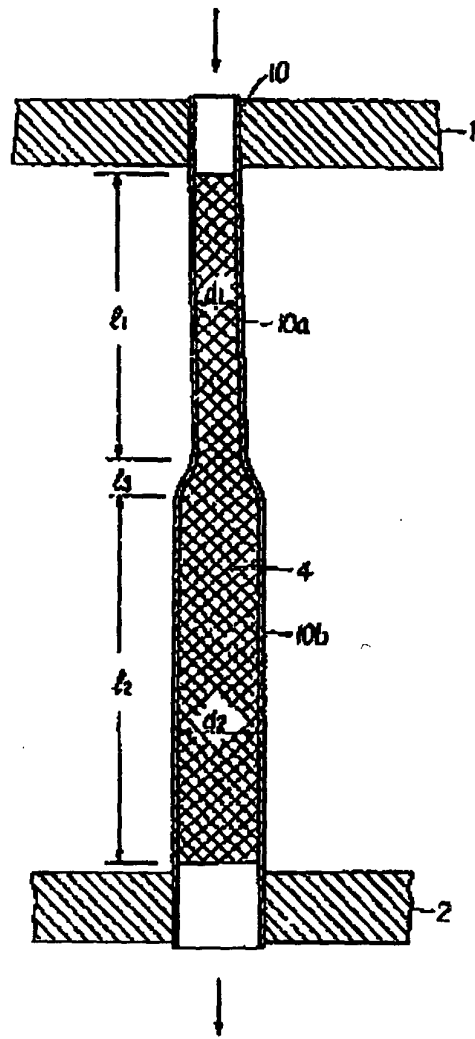


Fig. #2

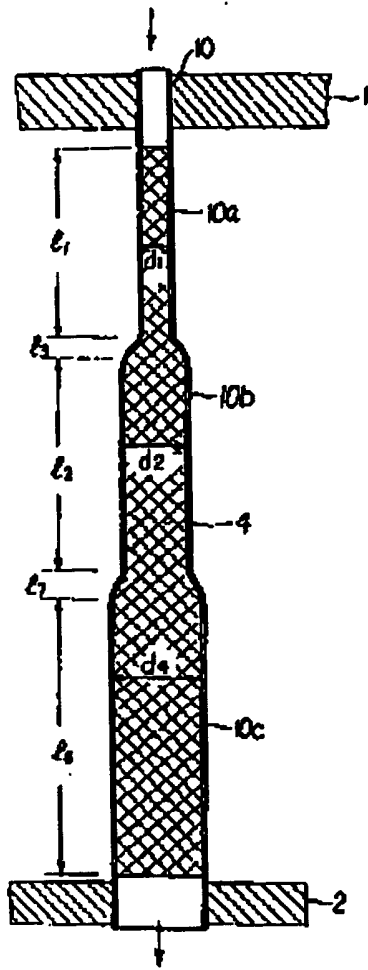


Fig. #3

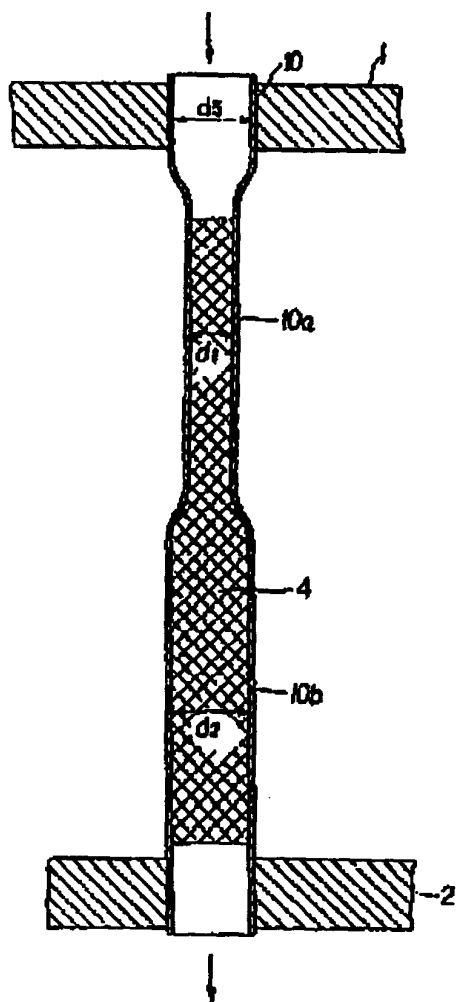


Fig. #4

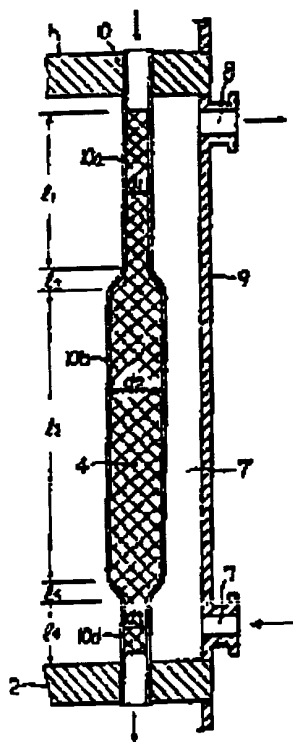


Fig #5

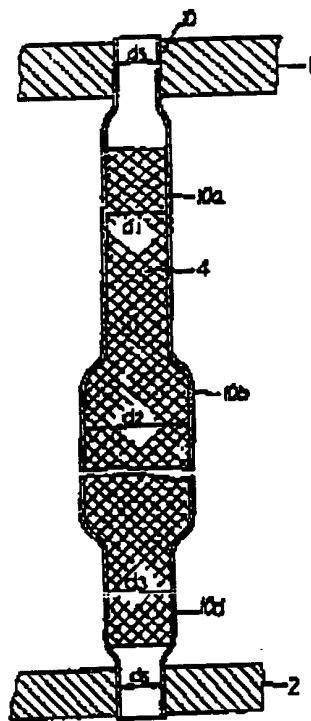


Fig. #6

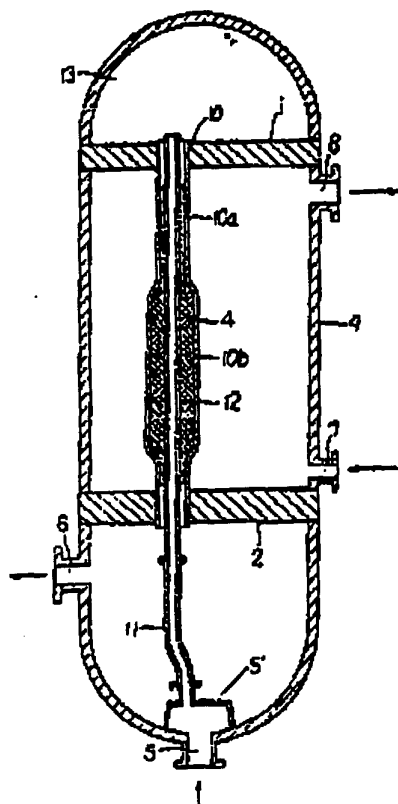


Fig #7

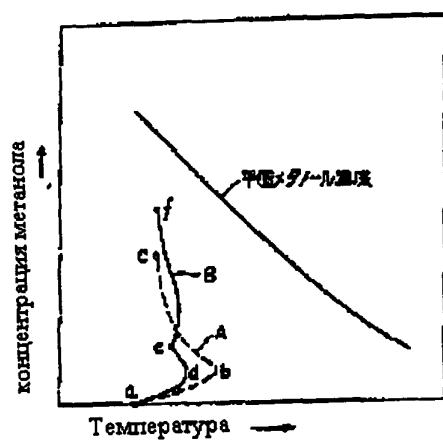


Fig. #8



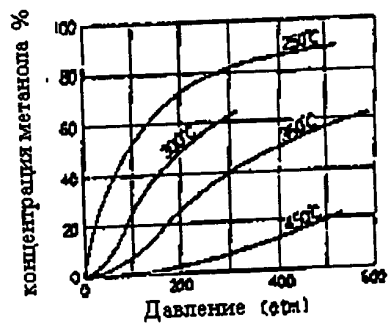


Fig. #9

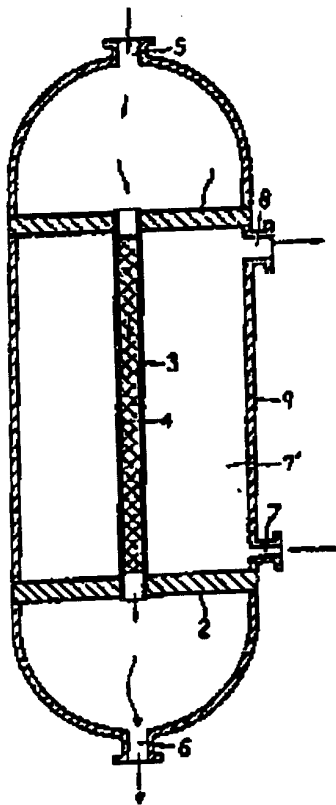


Fig. #10

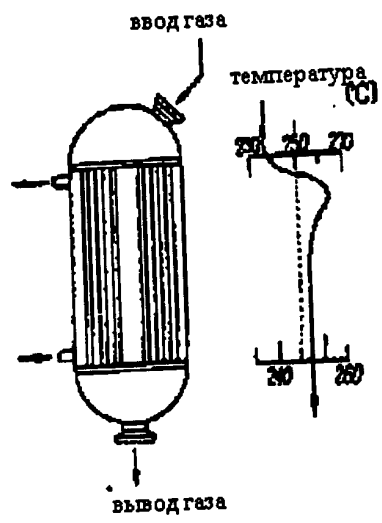


Fig. #11